International Journal of Civil Engineering and Technology (IJCIET)
Volume 8, Issue 3, March 2017, pp. 411–422 Article ID: IJCIET_08_03_042
Available online at http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=3
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

ANALYSIS OF STEEL BEAMS WITH CIRCULAR OPENING

Aparna C Manoharan
PG Student, Dept. of Civil Engineering,
National Institute of Technology Raipur, India

R.K. Tripathi
Professor, Dept. of Civil Engineering,
National Institute of Technology Raipur, India

ABSTRACT

Utilisation of Castellated beams has turned out to be exceptionally prominent nowadays because of its favourable structural applications. Steel beams having openings in the web portion is called as Castellated beams. The openings mostly made in the webs are hexagonal, diamond, circular or square in shape. One consequence of existence of web openings is the reduction of flexural and shear strength due to the development of various local effects. It also leads to a considerable decrease in the load carrying capacity of the beam. Therefore, the shape, size and location of the openings provided on the web are always an important issue of concern considering the structural performance of the beam.

In this work a comparative analysis of steel beams having different cross section has been done in which different loading and support conditions are considered. This work examines the effect of circular opening with different opening size on steel beams. The maximum stress and deflection pattern are studied analytically.

For this study ANSYS software have been used. Analysis showed that the steel beams have no significant effect on deflection due to the opening near the support. The Von Mises stress and shear stresses increase as the size of opening increases.

Key words: ANSYS, Circular openings, Steel beams, Deflection, Von Mises stress, Shear stress

Cite this Article: Aparna C Manoharan and R.K. Tripathi, Analysis of Steel Beams with Circular Opening. *International Journal of Civil Engineering and Technology*, 8(3), 2017, pp. 411–422.
http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=3

1. INTRODUCTION

The use of web openings has expanded significantly throughout most countries of the world in the past few decades. For supervision and maintenance of steel beams, openings are often inevitable and also for aesthetic reasons. Castellated beams and Cellular beams are steel beams with web openings; the fact that, there is an increase in depth of section without any add-on weight helps it achieve the advantage. Their web openings allow installation of electrical, mechanical and plumbing pipes and ducts within the depth of the beam. Therefore, it allows compact ceiling systems and maximised floor to ceiling heights. However, one consequence of the presence of web opening is its reduction in strength and will be prone to various local effects like buckling, shear and deformation. In recent times, a lot of research work has been carried out for the analysis and design of Castellated beams and Cellular beams [3]

In the present work the steel beams used are of different cross sections, i.e. Hollow Rectangular section, I section and Solid square section. This paper investigates the effect of a single web opening near one of the support on various structural aspects of beam and the effect on deflection and stresses with increase in the depth of web openings are analysed with the help of finite element analysis software ANSYS 14.

2. METHODOLOGY

The analysis of beams with circular shaped openings is carried out for different opening sizes and the result of the solid sections is compared numerically for the purpose of validation of the work. Finite element analysis is the best available method to analyse the steel beams with openings. With finite element modelling three-dimensional (3D) finite element models are developed to simulate the behavior of the steel beams with web opening. Modelling is done using the simulation software ANSYS 14.

2.1. Material properties

The properties of the material used to model the beam are in Table 1:

Table 1 Material Properties of Structural Steel

Sl/no	Material properties	Value
1	Density	7850kg/m^3
2	Young's modulus	200 GPa
3	Tensile yield strength	250 MPa
4	Poisons ratio	0.3

In this investigation, Rectangular Hollow shaped, I shaped and Solid square shaped cross sections are used. All the web openings are concentric to the mid-height of the sections. The parameters considered for the study is D/Do ratio of the opening and different boundary conditions where D is the overall depth of the beam and Do is the depth of the opening. Opening depth between 0.3 to 0.6D has been considered in the entire analysis. The variations in the parameters and corresponding cross-sections are mentioned in Table 2.

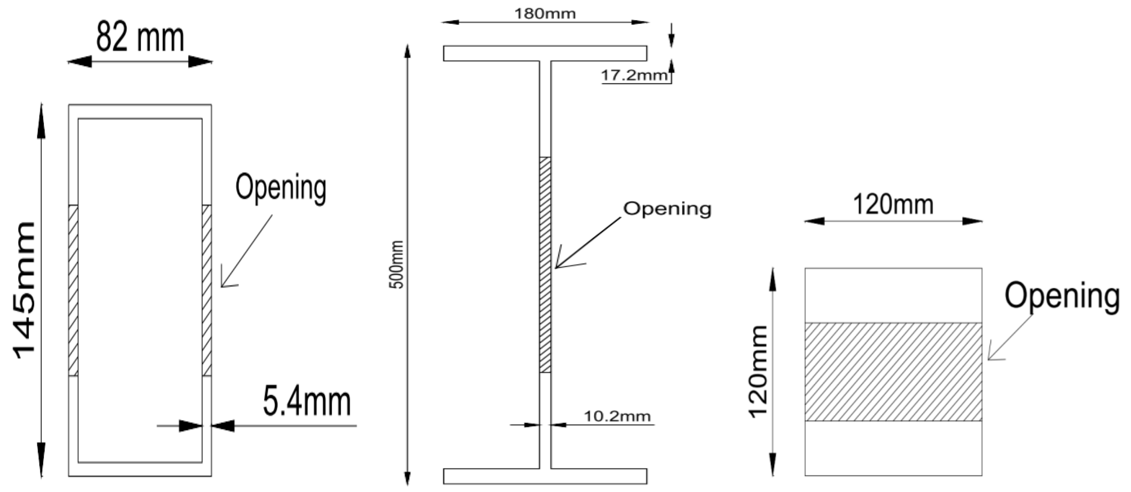
It should be noted that the beam geometry is defined using a Global Cartesian co-ordinate system. As displayed Fig 3, the depth of the beam is directed along the Y-axis and the longitudinal axis coincides with the Z-axis.

All the finite element models are discretized into a refined mesh of elements to obtain the accurate results.

3. MODELLING

In this work three types of sections are used to model the beam:

- Hollow Rectangular section (IS 4923-1997) (b) I-section (IS 800-2007) (c) Solid square section (IS 1732-1989)



(a) **(b)** **(c)**

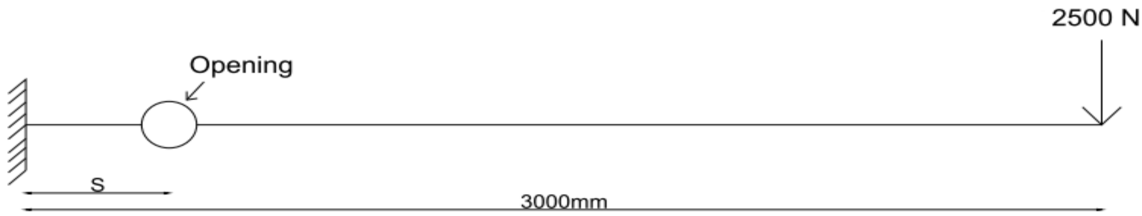
Figure 1 (a) Rectangular hollow section (b) I-Section (c) Solid square section

Each beam is provided with one opening near the support. The shape of the opening provided is Circular. The opening dimensions are given in Table 2. All the beams are of 3m span. The opening provided is concentric to the mid height of the sections.

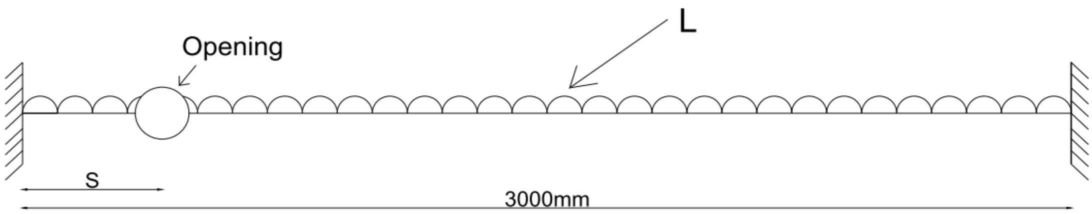
Three boundary conditions were adopted for all the sections (a) Cantilever beam (b) Fixed beam and (c) Propped cantilever beams

In order to study the effect, the analysis performed is divided into three cases:

Case 1: *Cantilever beam with point load of 2500 N at free end of the beam*



Case 2: *Fixed beam with a Uniformly distributed load*



Case 3: *Propped cantilever beam with a Uniformly distributed load*

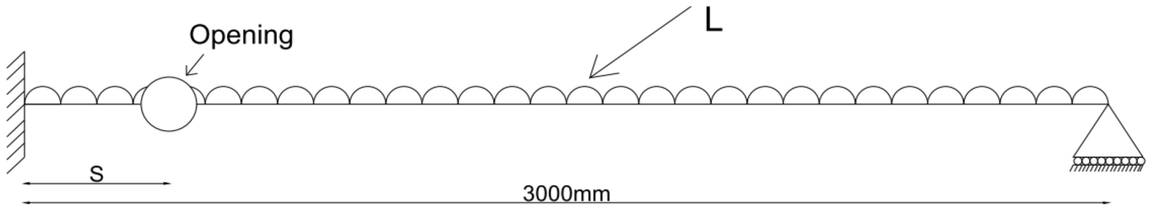


Figure 2 Loading and boundary conditions for all cases

- Hollow Rectangular section, L = 8.2 KN/m
- I-Section, L = 18 KN/m
- Solid square section, L = 12 KN/m

Uniformly distributed load of all the sections is equal to 0.1 MPa

Table 2 Details of beam sections, opening size and opening position

Selected sections	Circular opening size	Position of opening from support (S)
Hollow Rectangular section (145mm*582mm*5.4mm)	0.0D 0.3D 0.4D 0.5D 0.6D	100mm
I-Section (ISMB 500)	0.0D 0.3D 0.4D 0.5D 0.6D	200mm
Solid square section (ISSQ 120)	0.0D 0.3D 0.4D 0.5D 0.6D	100mm

4. VALIDATION

The stress and deformation values obtained numerically and analytically for the above mentioned cases are comparable. The FE model was validated against the numerical calculation and presented herein. Fig 3, 4 and 5 shows the stress distribution and deformation contour obtained from ANSYS.

4.1. Validation with numerical approach

Cantilever beam having Rectangular Hollow section without holes is taken as an example for the validation process. The maximum Deformation, Von-mises stress and Shear stress values of the above mentioned section obtained numerically are shown in Table 3:

Table 3 Validation with Numerical approach

Criteria	Numerical result	ANSYS result	% deviation
Deformation(mm)	17.32	17.352	0.18%
Von-Mises stress(MPa)	83.75	82.987	0.91%
Shear stress(MPa)	1.9669	1.9563	0.53%

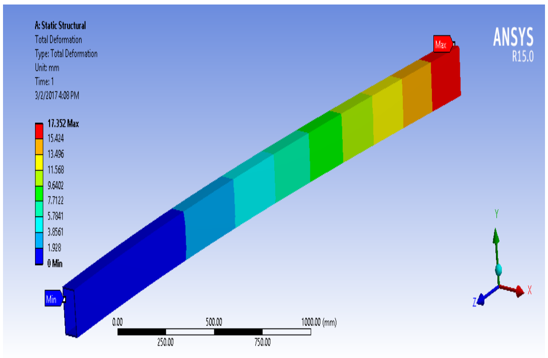


Figure 3 Deformation contour for Rectangular hollow sectional beam without holes

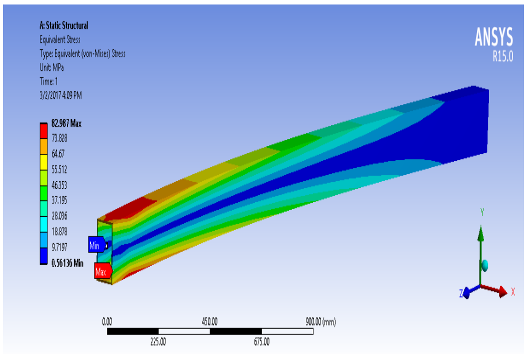


Figure 4 Von-Mises stress contour for Rectangular hollow sectional beam without holes

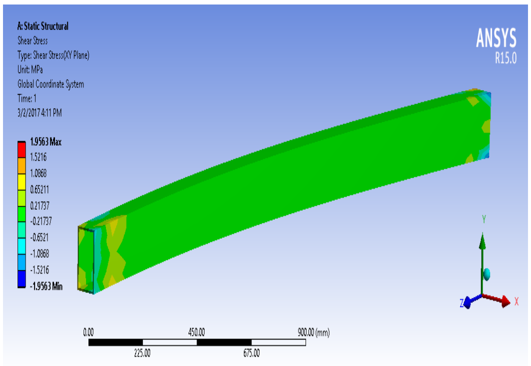


Figure 5 Shear stress contour of Rectangular hollow sectional beam without holes

5. RESULTS AND DISCUSSIONS

Deformation, Von-Mises stress and Shear stress results are arranged in a tabular manner to see the effects of web opening on different sections with different boundary conditions. Table 4,5,6,7,8,9,10,11 and 12 shows deformation and stress results of all cases in order.

Case 1: *Cantilever beam with point load of 2500 N at free end of the beam.*

Table 4 Deflection results for cantilever beam (in mm)

Opening size	Rectangular Hollow section	I-Section	Solid square section
Solid beam	17.352	0.2771	6.50
0.3D	17.404	0.2793	6.51
0.4D	17.43	0.2808	6.5283
0.5D	17.479	0.2832	6.556
0.6D	17.575	0.2873	6.6239

Table 5 Von-Mises stress results for cantilever beam (MPa)

Opening size	Rectangular Hollow section	I-Section	Solid square section
Solid beam	82.987	4.2923	28.321
0.3D	92.645	5.4802	28.469
0.4D	98.811	5.9301	28.681
0.5D	101.02	6.1288	28.87
0.6D	109.1	6.3802	33.465

Table 6 Shear stress results for cantilever beam (MPa)

Opening size	Rectangular Hollow section	I-Section	Solid square section
Solid beam	1.9563	0.5783	0.37252
0.3D	5.9938	1.1768	0.61247
0.4D	6.0552	1.2595	0.97192
0.5D	6.2875	1.2608	1.2563
0.6D	6.3766	1.4154	1.4001

It is evident from Table 4 that, opening near the support does not significantly effect the deflection at free end of cantilever beam. As shown in Table 5 and Table 6, Von Mises stress and Shear stress values increases as opening size increases, (i.e. decrease in the D/Do ratio).

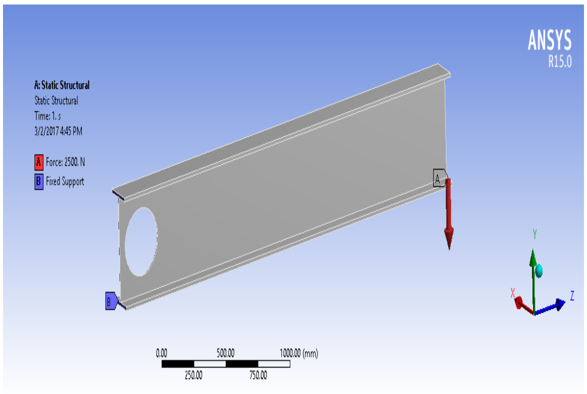


Figure 6 Load and boundary conditions for I-Sectional

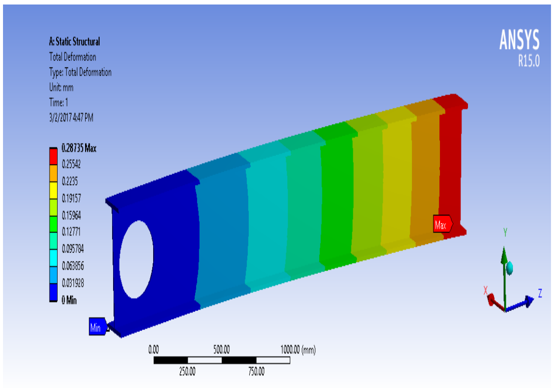


Figure 7 Deformation contour of I-Sectional beam beam (cantilever support)

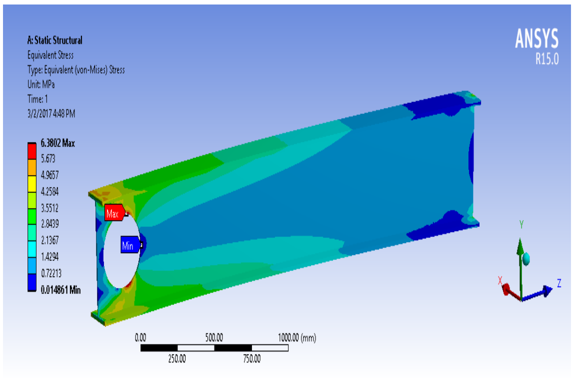


Figure 8 Von-Mises stress contour for I-Sectional

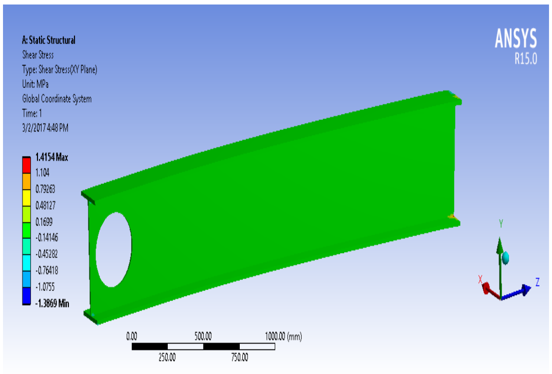


Figure 9 Shear stress contour of I-sectional beam beam

Case 2: *Fixed beam with a Uniformly distributed load.*

Table 7 Deflection results for fixed beam (in mm)

Opening size	Rectangular Hollow section	I-Section	Solid square section
Solid beam	1.4169	0.10374	0.73518
0.3D	1.4202	0.10927	0.74253
0.4D	1.4265	0.11431	0.74638
0.5D	1.4353	0.12178	0.75007
0.6D	1.451	0.13529	1.5138

Table 8 Von-Mises stress results for fixed beam (MPa)

Opening size	Rectangular Hollow section	I-Section	Solid square section
Solid beam	69.706	11.197	29.027
0.3D	82.57	21.841	32.34
0.4D	87.743	26.369	33.832
0.5D	101.99	31.514	38.403
0.6D	105.99	39.699	75.985

Table 9 Shear stress results for fixed beam (MPa)

Opening size	Rectangular Hollow section	I-Section	Solid square section
Solid beam	6.0908	1.1344	0.82981
0.3D	6.115	1.3215	1.4497
0.4D	6.1363	1.6178	2.0099
0.5D	6.4606	1.8977	2.2538
0.6D	6.9521	1.9081	2.5793

Here in this case, the variation of results is similar to that of case 1. From Table 7, it is clear that there is no significant effect on the mid span deflection of the beam due to the opening near the support. From Table 8 and Table 9, shows that the Von-Mises stress and Shear stress values increase with an increase in the opening area (i.e. decrease in the D/Do ratio).

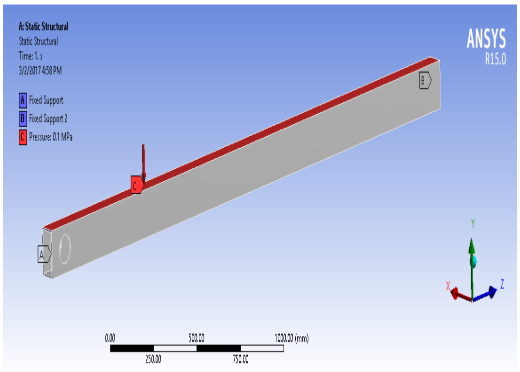


Figure 10 Load and boundary conditions for Rectangular hollow sectional beam (Fixed support)

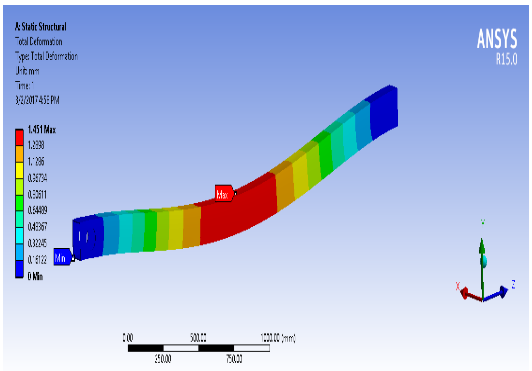


Figure11 Deformation contour of Rectangular hollow sectional beam

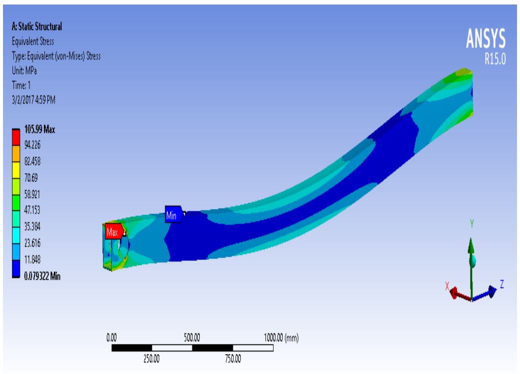


Figure 12 Von-Mises stress contour for Rectangular hollow sectional beam

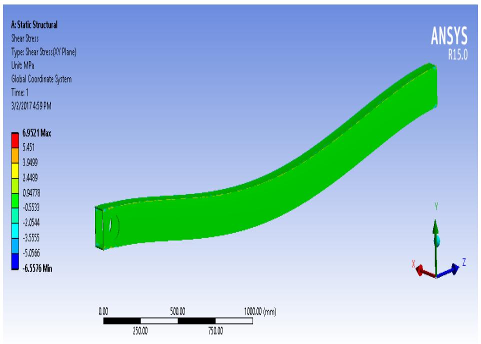


Figure 13 Shear stress contour of Rectangular hollow sectional beam

Case 3: *Propped cantilever beam with a Uniformly distributed load*

Table 10 Deflection results for propped cantilever beam (in mm)

Opening size	Rectangular Hollow section	I-Section	Solid square section
Solid beam	2.872	0.17221	1.5335
0.3D	2.8725	0.1764	1.5359
0.4D	2.882	0.1836	1.5434
0.5D	2.8973	019406	1.5518
0.6D	2.9239	0.21636	1.5713

Table 11 Von-Mises stress results for propped cantilever beam (MPa)

Opening size	Rectangular Hollow section	I-Section	Solid square section
Solid beam	102.09	17.035	46.174
0.3D	160.99	61.51	46.379
0.4D	218.77	63.58	49.253
0.5D	225.1776	64.13	50.674
0.6D	225.56	74.04	60.302

Table 12 Shear stress results for propped cantilever beam (MPa)

Opening size	Rectangular Hollow section	I-Section	Solid square section
Solid beam	9.599	3.1582	1.1283
0.3D	10.044	8.279	1.3882
0.4D	11.032	10.166	1.8318
0.5D	11.37	10.226	2.9719
0.6D	11.407	11.604	2.982

From Table 10, it is clear that for this case there is no significant effect on the mid span deflection of the beam due to opening near the support. In Table 11, considering Rectangular hollow section, it can be seen that the Von Mises stress value for 0.6D opening size is near to the yield strength i.e. 250MPa and, hence it can be considered as a critical value for the section. Table 11 and Table 12 shows the variation of Von-Mises stress and Shear stress values, which increases with an increase in the opening area (i.e. decrease in the D/Do ratio).

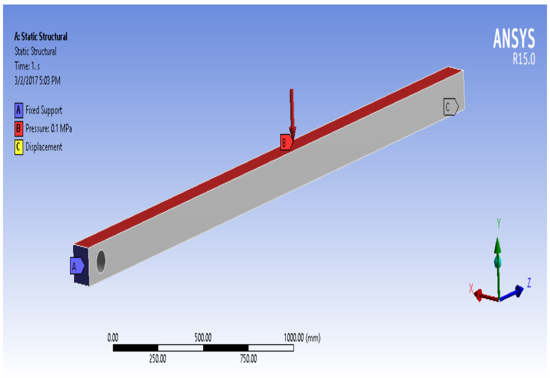


Figure 14 Load and boundary conditions for Solid Square sectional beam (Propped cantilever support)

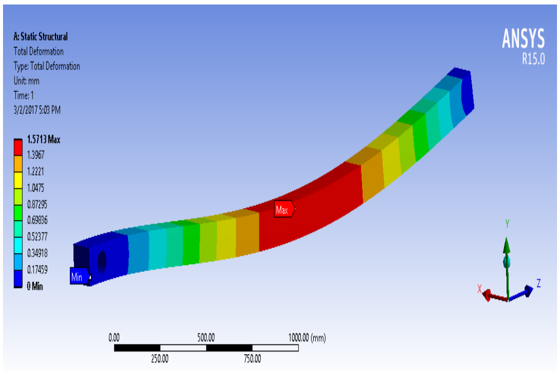


Figure 15 Deformation contour of Solid square sectional beam

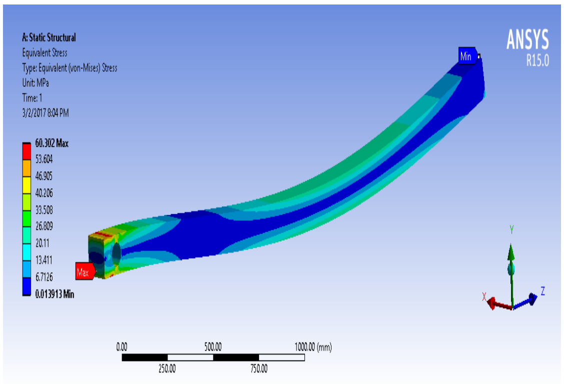


Figure 16 Von-Mises stress contour for Solid square sectional beam

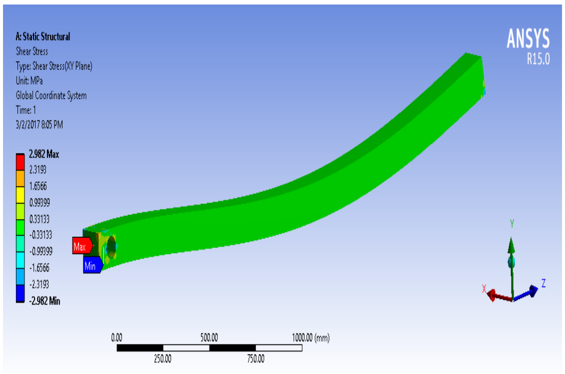


Figure 17 Shear stress contour of Solid square sectional beam

6. CONCLUSION

The analysis of steel beams with a web opening for deflection and stresses is done using ANSYS software. The purpose of this study was to evaluate different sections of the beam with a web opening near to the support. Therefore a number of analysis are carried out on steel beams with different sections. Based on the results of the analysis done, the following findings and conclusions are made:

- Analytical results show that there is no much variation in the deflection values when compared with solid beam results for all the cases considered.
- It is concluded that as the depth of opening increases, stress concentrations increases at the opening boundaries.
- The steel beams have no significant effect on deflection due to the opening near the support in all the cases considered.
- Perforations caused an increased Von-Mises stress in the web above the opening due to the reduced Section moduli and shear area.
- As the opening provided is of Circular shape, in all respect it was very effective, like it shows less stress concentrations at the web openings and will be easy to fabricate.

It can be concluded that, the finite element analysis using the ANSYS software is capable of predicting the results up to a reasonable degree of accuracy.

REFERENCES

[1] Samadhan G. Morkhade, Laxmikant M. Gupta, (2015) “An experimental and parametric study on steel beams with web openings” International Journal of Advanced Structural Engineering

[2] Donghua Zhou , Longqi Li , Jürgen Schnell , Wolfgang Kurz , Peng Wang ,(2012), “Elastic Deflections of Simply Supported Steel I-Beams with a Web Opening, Elsevier

[3] Jamadar A M, Kumbhar P.D (May 2015) “Parametric study of Castellated beam with Circular and Diamond shaped openings” International Research Journal of Engineering and Technology, Volume: 02, Issue: 02

[4] D Darwin, (2000) “Design of composite beams with web openings” Journal of Structural Engineering (ASCE)

[5] B.Anupriya, Dr K Jagadeesan(2014) “Shear strength of Castellated beam with and without stiffeners using FEA(ANSYS 14)” Internal Journal of Engineering and Technology(IJET)

[6] Vimalkumar A. Patel, Vipul R. Patel ,Vasant S. Patel , Bhavesh C. Pathak (2013), “Effect of Different Web Openings in Narrow Flange I Section Beam, International Journal of Engineering Research & Technology (IJERT), Vol. 2 Issue 11

[7] M.R.Wakchaure, A.V.Sagade, “Finite Element Analysis of Castellated Steel Beam”, (2012),International Journal of Engineering and Innovative Technology (IJEIT), Volume 2, Issue:1

[8] Sharda P. Siddh , P.D. Pachpor, “Finite Element Analysis of steel beam with web opening of different shapes”(July 2011), International Journal of Science and Advanced Technology (ISSN 2221-8386), Volume 1

[9] Miss Komal S. Bedi, Mr. P.D.Pachpor. “Moment and Shear Analysis of Beam with Different Web Openings”. International Journal of Engineering Research and Applications, Vol. 1, Issue 4, pp. 1917-1921

[10] Mohammad a. A. Alsarraf and Hamdy Shehab El Din, The Effective width in Multi-Girder Composite Steel Beams with Web Openings, International Journal of Civil Engineering and Technology (IJCIET), Volume 5, Issue 9, September (2014), pp. 260-265.

[11] Nakka Sita Rama Raju, V Jaya Prasad, S Kamaluddin and A Sunny Kumar. Thermal Analysis of Shell and Tube Type Heat Exchanger to Demonstrate the Heat Transfer Capabilities of Various Thermal Materials Using Ansys. International Journal of Mechanical Engineering and Technology, 8(2), 2017, pp. 160–166.

[12] Rakesh Jaiswal, Anupam Raj Jha, Anush Karki, Debayan Das, Pawan Jaiswal, Saurav Rajgadia, Ankit Basnet and Rabindra Nath Barman. Structural and Thermal Analysis of Disc Brake Using Solidworks and Ansys, International Journal of Mechanical Engineering and Technology, 7(1), 2016, pp. 67-77.

[13] Flavio Rodrigues, Pedro C. G. da S. Vellasco, Luciano R. O. de Lima, Sebastião A. L. de Andrade, (2014), Scientific Research.